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COMPUTATION METHODS FOR INFRARED IMAGING GUIDANCE TRACKING

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ABSTRACT

This article describes in detail computational methods for infrared imaging guidance tracking and their advantages and disadvantages. It also lists their applications in strategic weapons. This article introduces some new imaging tracking computational methods and points out developmental trends in infrared imaging guidance tracking computational methods and their important place in modern warfare.

I. Forward

Infrared tracking was used in tactical weapons back in the fifties. Infrared guidance is currently the most commonly used form of guidance in precision guided weapons. Because of increased tactical requirements and the tremendous developments in component technology and computational technology, infrared guidance technology has received a great deal of attention. Infrared imaging guidance technology became an actual reality in the mid-seventies. This was primarily due to the tremendous advances in infrared technology. Advances appeared one after another, such as the mercury cadmium telluride array element, the infrared focal plane array, and the gradual feasibility of the infrared fixed gaze array technology all laid the way for infrared imaging guidance technology.

The use of infrared imaging guided weapons not only permits achieving omnidirectional attack and absolute fire-and-forget, but such weapons also have automatic target search, capture,

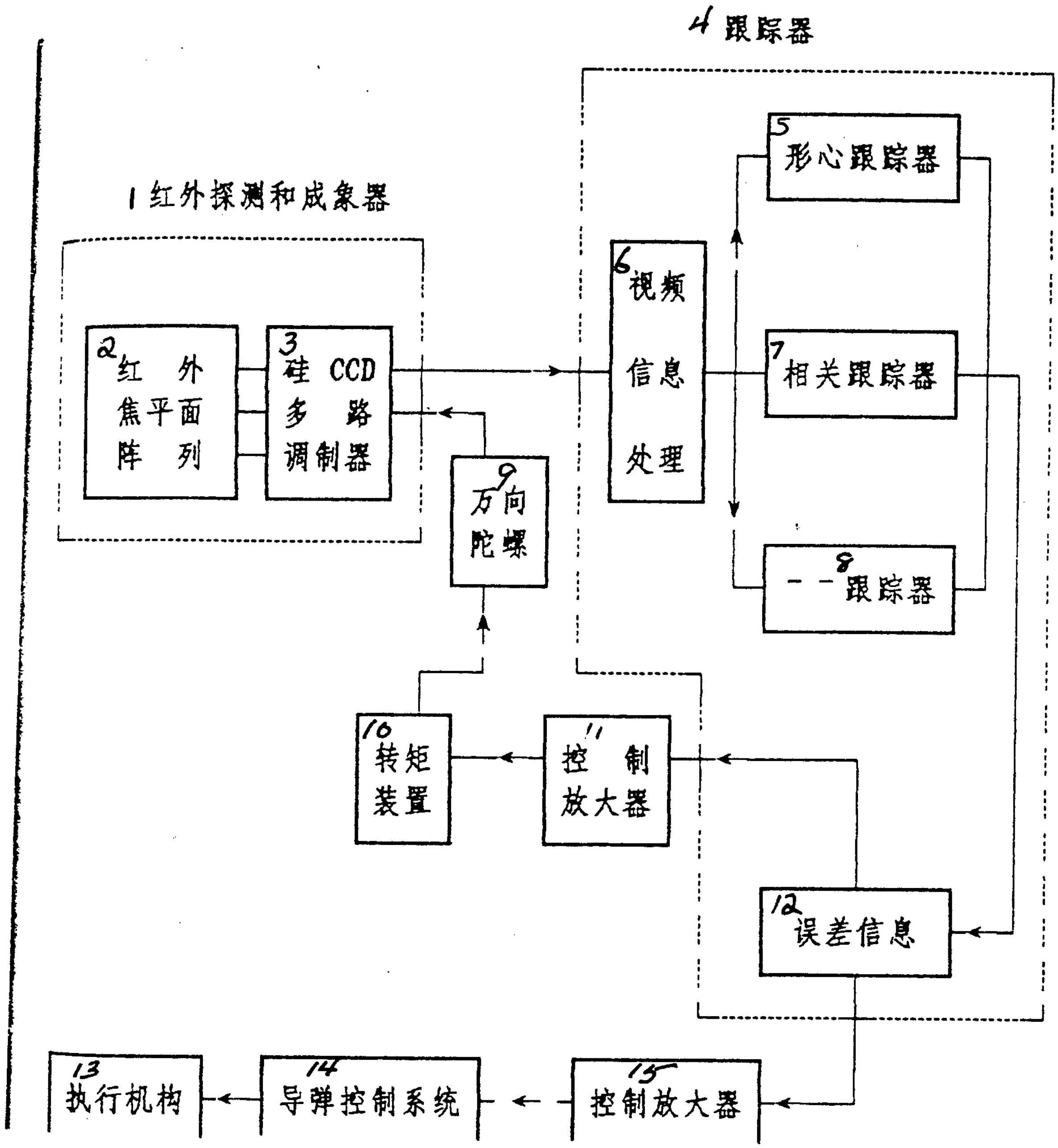
recognition, tracking and guidance capability.

Characteristics of infrared imaging guidance technology are

- It has fire-and-forget capability.
- It has automatic target recognition and tracking capability.
- It has strong all-weather combat capability and anti-jamming capabilities
- It has the capability to fight groups of targets at once.
- Because it is passive, guided weapons themselves are difficult for the enemy to detect.

The principles of infrared imaging guidance is shown in Figure 1.

Fig. 1. The principles of infrared imaging guidance



1. Infrared detector and imager. 2. Infrared plane array. 3. Silicon CCD multichannel modulator. 4. Tracker. 5. Centroid tracker. 6. Visual frequency information processing. 7. Correlation tracker. 8. Tracker. 9. Gyroscope. 10. Ranging equipment. Control amp. 12. Error information. 13. Executor. 14. Missile control system. 15. Control amp.

One of the key technologies of infrared imaging guidance is imaging tracking computation.

II. Imaging tracking computations

Trackers using imaging sensor design are called imaging trackers. Imaging sensors are a type of sensor which use a single or multiple element detectors. The detectors do a linear wide grid scan of the target background, generating a video signal. Imaging tracking can basically be divided into wave gate video tracking (GVT) and correlation tracking. Gate trackers can determine that a certain portion of the background received is the target image and generate tracking signals from the identified target information. In general, determination of the target is accomplished through the use of electronic wave filters, selective gates and light imaging operations. Correlation trackers determine tracking signals based on the correlation factors between the image produced by calculation sensors and stored reference images. The tracking point is the location where the two images have the best match, that is, the peak number of correlation factors.

1. Wave gate video tracking computation

In infrared tracking systems, the wave gate (electronic window) is one means of video signals processing which is already in widespread use. The wave gate tracking system is designed on the basis of the principle of correlation between the lines and fields of video signals. The wave gate tracking computation can be divided into centroid tracking computations, boundary tracking computations, dual boundary center tracking computation and zone balanced tracking computation. Centroid tracking computation can be further divided into center of gravity tracking computation and center of brightness tracking computation.

A. Centroid tracking computation

So-called centroid tracking is the determination of the target location from the center of gravity or center of brightness of the target image. For a uniform two dimensional target center of gravity tracking computation can be used. For a light emitting, nonuniform target, center of brightness computation can be used.

The error for center of gravity tracking is:

$$e_x = A_t^{-1} \int\int xS(x, y)\,dxdy$$

$$e_y = A_t^{-1} \int\int yS(x, y)\,dxdy$$

Wherein, the area of the target $\mathbf{A}_t$ is defined as

$$A_t = \int\int S(x, y)\,dydx$$

and $\mathbf{S(x,y)}$ are the target factors.

The error for center of brightness tracking is

$$e_x = M^{-1} \int\int xI(x, y)\,dxdy$$

$$e_y = M^{-1} \int\int yI(x, y)\,dxdy$$

Wherein **M** is total energy and **I** is the target brightness factor.

The advantages of centroid tracking computation are: Computations are simple, can provide constant gain, and are not restricted by linear tracking video frequencies. Its disadvantages are: Centroid trackers are fairly seriously affected by violent movements by the target and when the target is covered. Violent movement by the target often causes the target to quickly move away

from the center of the wave gate, resulting in the loss of the target. When the target approaches another object, the characteristics of both objects often enter the wave gate, forcing the brightness center to move toward a point between the two objects, which is the so-called "sighting point fluctuation". Also, target center of gravity also often "shifts" with changes in target heading and transparency. This shift cal lead to loss of target, and "sighting point fluctuation" is one of the primary errors of long distance tracking systems. The United States AGM-65D CALF air-to-ground infrared imaging guided missile uses a type of center of gravity tracking.

B. Boundary tracking computation

Boundary tracking computation is one of the simplest methods of computation. It is suited for fixed wave gate intensity trackers. It selects the target's boundary points (upper, lower, left and right) as tracking points, causing the wave gate to lock onto these points to inhibit background and other portions of the target. This principle of this method of computation is to take advantage of the marked changes in brightness where the target and the background meet, and target position information can be obtained through differential methods. The disadvantages of boundary trackers are that they are vulnerable to jamming and their precision is fairly low.

C. Dual boundary tracking computation

Boundary tracking can be extended to become dual boundary tracking, that is, the target location is the center between two boundaries.

$$x_o = \frac{x_{右}^{R} - x_{左}^{L}}{2}$$

$$y_o = \frac{y_{下}^{B} - y_{上}^{T}}{2}$$

X_R, X_L, Y_B and Y_T are the values at the right, left, bottom and top boundaries of the target.

This is more precise than boundary tracking computation, and is suited for tracking symmetrical targets or point source targets.

D. Zone balancing method

This method is one which uses the calculation of area, equalizing the target area on either side of the center of the wave gate. The limitations of this method can be seen in the reliance of target error characteristics on the size and shape of the target. Dynamic characteristics of the tracking circuit are very intensely tied to tracker gain.

2. Correlation tracking computation

The relative positional shift of the same object in two images is measured by the correlation tracker, with one image called the reference image, which can represent the previous measured value, and the other image is called the reception image, usually obtained by sensors observing this actual object. Correlation trackers, through comparing current objects with stored references (previous frame images) and determining the positional shift between the two, allow for better utilization of image clarity. The correlation trackers can provide better tacking capabilities under conditions

of low signal-to-noise conditions. They are best suited for use in homing missiles. When a missile approaches the target, and the size of the target image exceeds the field of view of the tracker, the correlation tracker can be used to track certain details within the target and to maintain a stable terminal tracking point, overcoming wave gate visual tracker blind spots. Correlation trackers can also be used to align missiles with target acquisition systems with other sensors.

When using correlation tracker computation, the stored reference image is **S(x,y)** with the entire **S** zone already defined. The received image is **r(x,y)**, and there are some discrepancies between it and the stored image and it includes some noise. It may be expressed as:

$$r(x, y) = AS(x - x_0, \; y - y_0) + n(x, y)$$

In this equation, **A** is an unknown constant, (x_0, y_0) are the horizontal and vertical shift between **S** and **r**. **n** is noise. Image **r** is defined within zone **R**, and is usually larger than **S** and includes **S**. The tracking circuit can shift the axis of the sensor so the signals it receives **r(x,y)** aligns with the stored reference **S(x,y)**, thus forcing (x_0, y_0) to be zero. This will necessarily form error signals ε_{tx} and ε_{ty}. Furthermore, ε_{tx} and ε_{ty} are the best estimates of tracking error x_0 and y_0. The cross correlation factor between **S** and **r** is:

$$C(x, y) = \frac{\int\int S(u, v)\, r(u+x, v+y)\, du dv}{\{\int\int [S(U, V)]^2 du dv \int\int [r(u, v)]^2 du dv\}^{1/2}}$$

In this equation, the range of integration is within the **S** zone. However, correlation trackers of different design have different methods of estimating the maximum location of **C(x,y)**.

The most obvious design scheme is the direct calculation of **C**(x,**y**) within **x** and **y** values with sufficient errors x_0 and y_0 and taking the coordinates of the maximum value of **C(x,y)** to be the error signal. However, this method requires a great deal of calculation, and a more suited method is the average absolute differential correlation. This digitized the reference image and the received image, and calculates the matching error factors of the two images. $\Sigma|S(i,j)-r(i,j)|, i,j \epsilon S$, under ideal conditions with no noise, only the zero point of the factors need to be found. Under actual conditions, it is only necessary to align the error factors smaller than a positive threshold to find the matching point - target location. This method is simple and quick. Correlation trackers are capable of obtaining more image information than wave gate trackers. They can also be used to track fairly small targets or to track targets and to track targets with relatively poor comparability. It is a tracking device currently in widespread use. The disadvantages of correlation trackers are their structural complexity and the possibility that they can be seriously affected by drastic movements by the target, target azimuth, , changes in transparency and strong jamming.

The United State's AGM-86B cruise missile and West Germany's "Cuigete" (phonetic) infrared imaging missile use correlation methods.

3. Multimode tracking computation

Modern warfare requirements that trackers be capable of tracking multiple targets to maximize the combat capabilities of weapons systems have brought out new multimode tracking methods, allowing a number of trackers to operate in parallel, with a main controller selecting tracking control signals based on the believability of the data from individual trackers.

An automatic target tracking and recognition status tracker (SOA) which has just come out is a typical multimode tracker which uses self-adapting micro information processor technology. The SOA tracker typically combines a number of computational methods. These methods include correlation, center of shape, boundary detection, movement detection and conventional model noise wave compensation. Each model can track very well under certain conditions, and under certain special conditions tend to fail. Compared to single mode trackers, multimode trackers can better maintain tracking characteristics. We have frequently discovered that when the believability of a certain tracking mode is low, another type of tracking mode with better believability can be used.

Multimode tracking can be achieved by the following two methods. In earlier methods, the tracker and the operator worked together, with the tracker alerting the operator when a target was about to be lost, and then the operator selecting another tracking mode. In newer methods, the controllers evaluates each tracking computational method, determining the believability of the different tracking modes and automatically selecting the mode with the best believability. In can be predicted that multimode tracking computational methods will be able to markedly reduce the probability of losing a target once locked on.

The SOA tracker has a self-adapting wave gate which can maximize inclusive target information and eliminate background. (Translator's note: Left-most character on each line of this page [7] is not reproduced. When character can be derived from context it will be placed in parenthesis and, and when it cannot, it will be noted as illegible). (When) there is a high target comparability, the self-adapting wave gate operates very well. However, in regions of high noise waves and with the low target

(comparability), the self-adapting wave gate is difficult to establish. Another characteristic of the SOA tracker is that it has conventional model (noise) wave compensation. This type of computation uses a priori velocity signals, and has the tracker short (one character illegible) "block" (this block usually causes the lock-on to be broken), and is recaptured when it reappears. This method (works) fairly well when the direction and velocity of the target remains unchanged. However, in environments with a fairly high level of noise waves, the SOA tracker can also have problems. For example, assume a target enters a (high) noise wave zone, the fluctuations in the tracker believability force the system to enter a new capture mode. At this time the conventional model noise wave (compensation) mode comes into play, and the tracking wave gate changes its width to re-acquire the target. However, if a noise wave object enters the tracking (one character illegible), it will have a marked effect on the tracking computational method, and this will often cause the system to lock onto the noise wave object and not the actual target. The added factors generating an effect on computational (methods) include: low signal-to-noise ratio, the angle of incidence and background characteristics.

The prominent advantages of the properties of systems using multi-mode computational methods are:

(1). Subject stability for target acquisition.

(2). Capable of stable tracking with a fairly high degree of surface object noise.

(3). Has fairly strong capability to counter optical jamming.

(4). Has fairly good instantaneous inhibition of launched and flight jamming.

(5). Strong automatic target acquisition capability.

(6). Has the capability to recapture targets temporarily lost.

(7). It can guide missiles to the center of gravity of targets inside the classical blind zone.

The infrared imaging "Harpoon" air-to-ground missiles used by the United States during the Gulf War used center of gravity self-correlating tracking mode. The United States AGM-114 "Hellfire" air-to-ground, ground-to-ground infrared imaging missiles used self-adapting wave gate center of shape tracking and correlation trackers.

4. A number of new wave gate tracking computational methods

In addition to the computational methods mentioned above, there are a number of new computational methods currently being developed.

A. Self-adapting wave gate tracking computation

This method uses weighted believability to describe target violent movements and under strong jamming conditions to provide correction to the position and size of the wave gate under disadvantageous conditions, allowing the self-adapting wave gate tracker be able to provide a certain degree of tracking under abnormal conditions as well as be able to track targets under normal conditions.

B. Point mode fuzzy relaxation matching imaging tracking computation

Select a supplemental characteristic of the target. This characteristic has rotational, amplification and horizontal constancy. Using the center of gravity in the target zone to constitute the point mode, a reference vector concept is introduced to accelerate the computational speed. Introducing the vector

space (one character illegible) using average differential minimum criterion to derive the degree of similarity factor of the space structural relationship. Then, use the supplementary vector to perform the fuzzy matching iterative process, until the process stabilizes.

C. Differential image tracking computation

This is statistical calculation of two sample images within a specific time interval, directly obtaining estimates of the image shifts between the two sampling intervals. Compared to other methods, this method has less computations, requires smaller memory and is better for live time computations.

D. Intelligent target tracking computations

In order to attain zero lost lock-on capability, intelligent target trackers will be able to combine target instructions and target tracking computation, and through combining target instruction devices and tracking devices, they will be able to bring about the development of fully automatic trackers. Intelligent target tracking computation is accomplished on the basis of automatic target recognition, thus being able to accomplish target acquisition, recognition and tracking without human assistance, and allowing missiles to become fully "fire and forget" weapons.

III. Conclusions

In order to meet the requirements of future wars, the developed western nations are continuing to work on improving infrared imaging tracking technology. This technology is primarily determined by the level of detectors and information processing

technology. Because information processing technology is the heart of infrared tracking technology, while improving the device technology, attention must also be paid to information processing technology. Form the current state of development it can be predicted that by the year 2000 foreign fixed vision intelligent infrared imaging missiles will be in the lead, replacing the various current infrared missiles. at that time, infrared imaging missiles will be able to detect, locate, recognize and categorize all targets within the field of view, prioritize these targets, and select which targets to attack. They will also be able to track a number of targets at the same time and to selectively track high priority targets. Against a complex backgrounds, they will be able to predict characteristic changes of a target being covered and after being covered, and take steps to deal with this, ensuring that the target is not lost. Should a target be lost and reappear within the system's field of view, the missile will be able to reacquire and track the target. They will also be able to select vital or weak points on the target to attack, maximizing their power. They will also attack the targets by the best route. The entire infrared image guidance head will be miniaturized, combining miniaturization with automation. This computation method is the foundation for achieving this objective.